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(54) **RADICAL SET DETERMINATION FOR HMM BASED EAST ASIAN CHARACTER RECOGNITION**

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G06K 9/62 (2006.01)

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(58) **Field of Classification Search** ..... None
See application file for complete search history.

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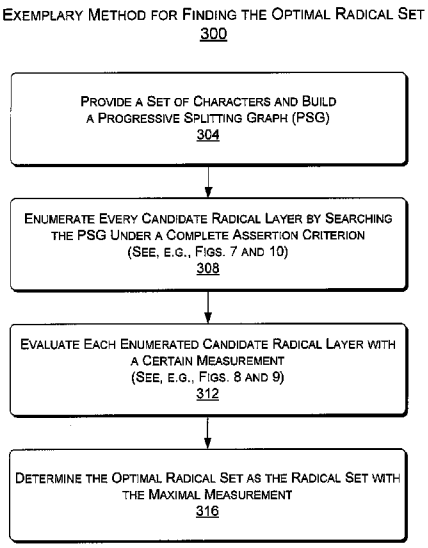
(57) **ABSTRACT**

Exemplary techniques are described for selecting radical sets for use in probabilistic East Asian character recognition algorithms. An exemplary technique includes applying a decomposition rule to each East Asian character of the set to generate a progressive splitting graph where the progressive splitting graph comprises radicals as nodes, formulating an optimization problem to find an optimal set of radicals to represent the set of East Asian characters using maximum likelihood and minimum description length and solving the optimization problem for the optimal set of radicals. Another exemplary technique includes selecting an optimal set of radicals by using a general function that characterizes a radical with respect to other East Asian characters and a complex function that characterizes complexity of a radical.

18 Claims, 16 Drawing Sheets



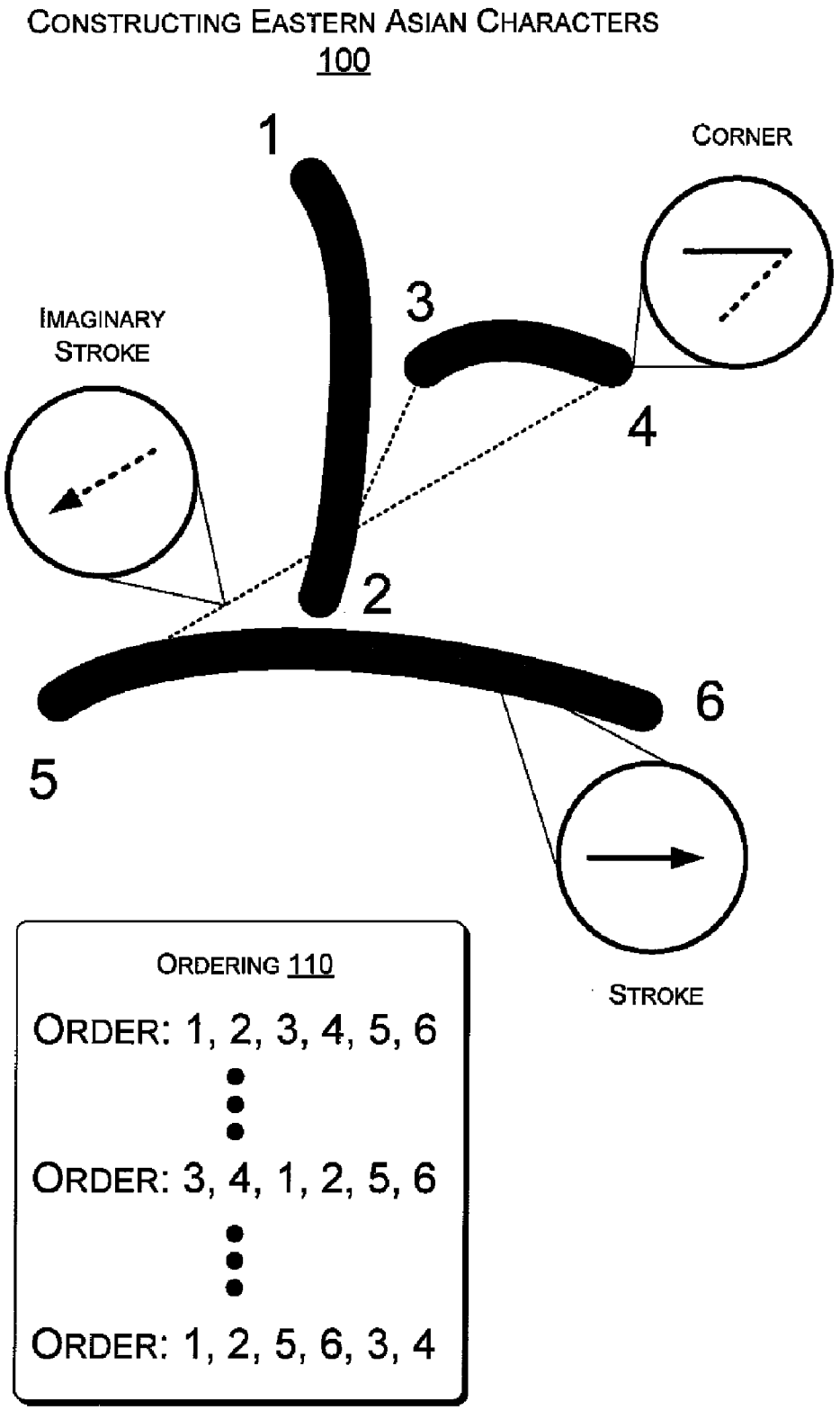

CONSTRUCTING EASTERN ASIAN CHARACTERS
100
1
CORNER
IMAGINARY STROKE
3
4
2
6
5
STROKE
ORDERING 110
ORDER: 1, 2, 3, 4, 5, 6
ORDER: 3, 4, 1, 2, 5, 6
ORDER: 1, 2, 5, 6, 3, 4

FIG. 1

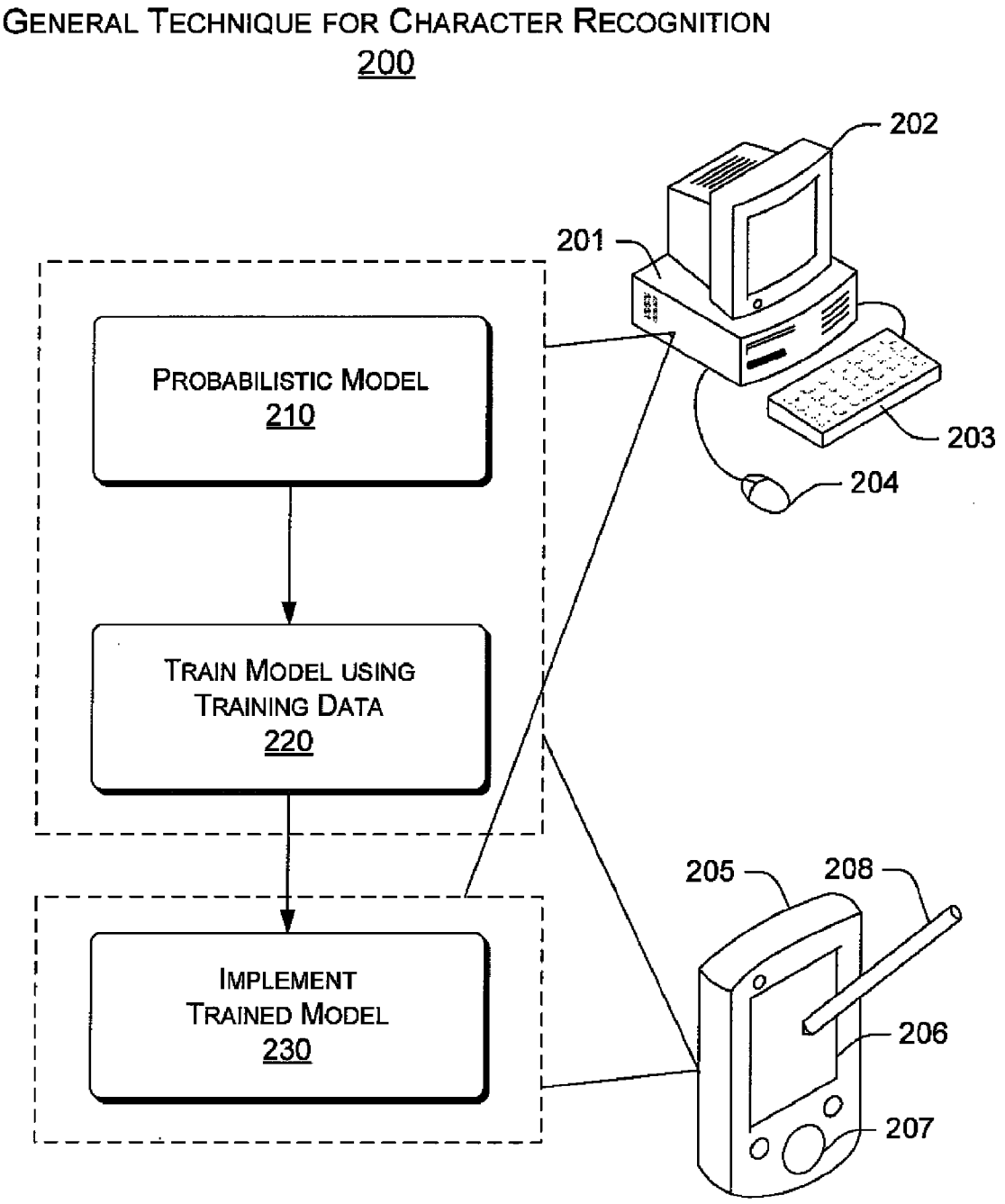

GENERAL TECHNIQUE FOR CHARACTER RECOGNITION
200
202
201
PROBABILISTIC MODEL
210
203
204
TRAIN MODEL USING
TRAINING DATA
220
205
208
IMPLEMENT
TRAINED MODEL
230
206
207

FIG. 2

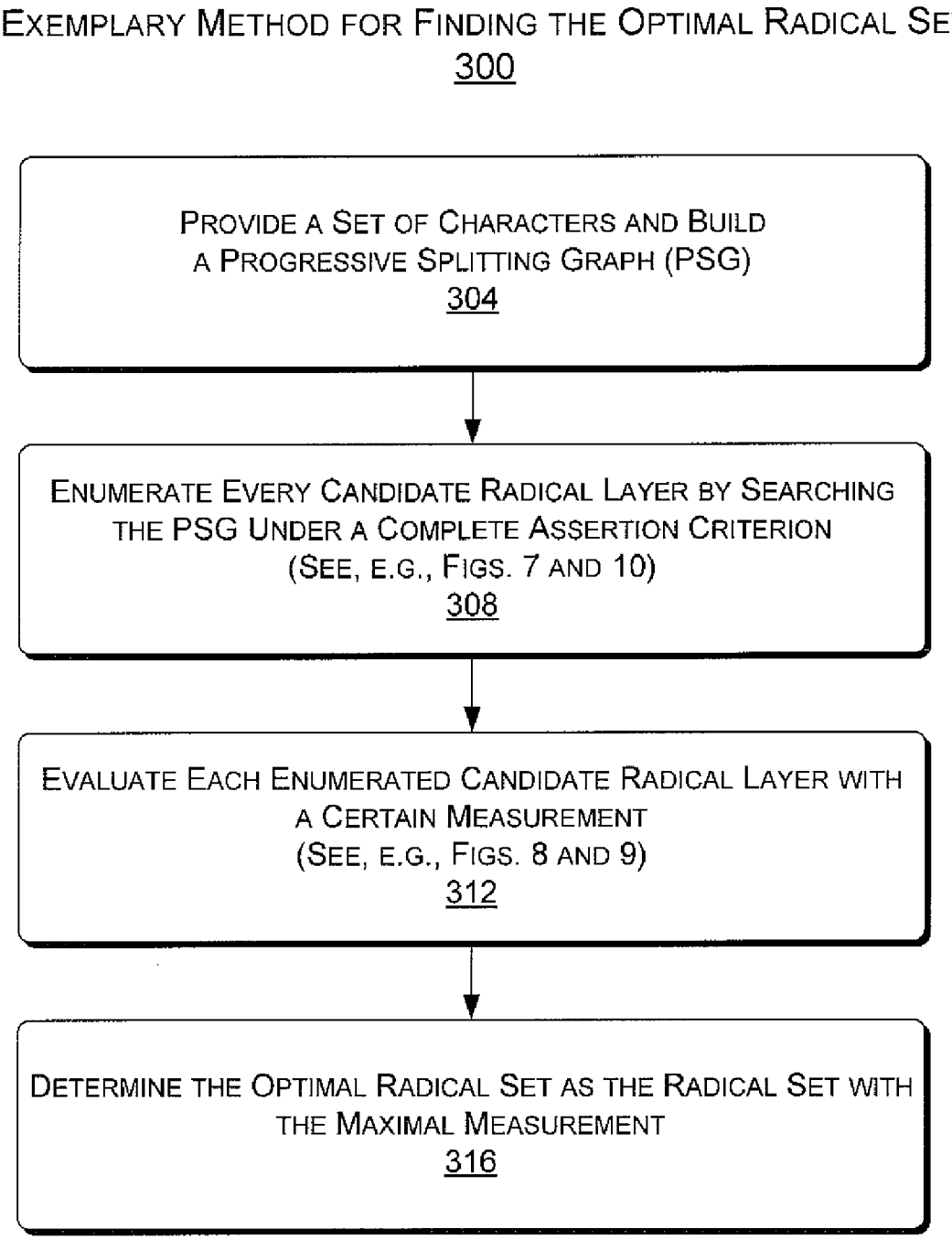

EXEMPLARY METHOD FOR FINDING THE OPTIMAL RADICAL SET
300
PROVIDE A SET OF CHARACTERS AND BUILD A PROGRESSIVE SPLITTING GRAPH (PSG)
304
ENUMERATE EVERY CANDIDATE RADICAL LAYER BY SEARCHING THE PSG UNDER A COMPLETE ASSERTION CRITERION (SEE, E.G., FIGS. 7 AND 10)
308
EVALUATE EACH ENUMERATED CANDIDATE RADICAL LAYER WITH A CERTAIN MEASUREMENT (SEE, E.G., FIGS. 8 AND 9)
312
DETERMINE THE OPTIMAL RADICAL SET AS THE RADICAL SET WITH THE MAXIMAL MEASUREMENT
316

FIG. 3

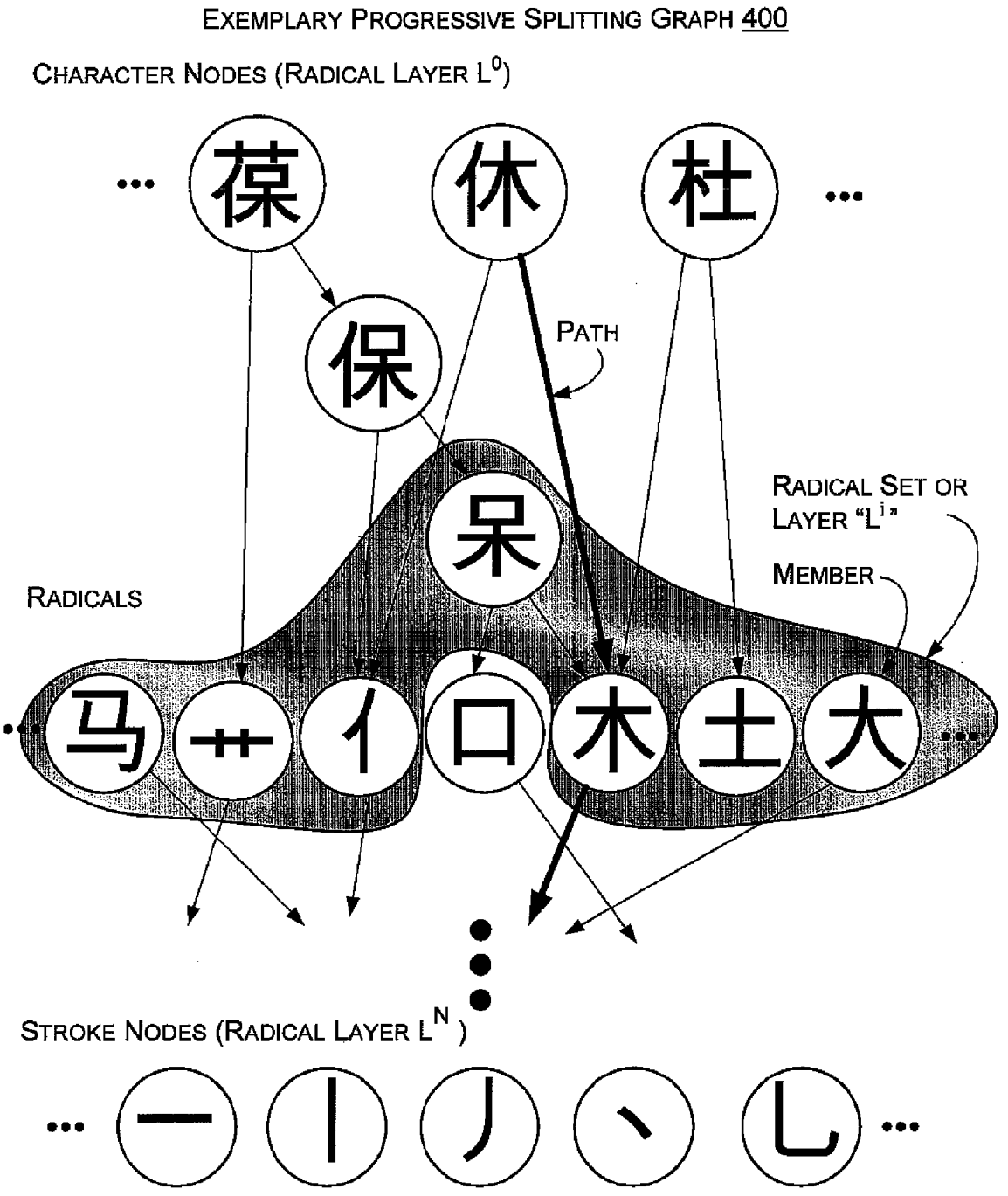

EXEMPLARY PROGRESSIVE SPLITTING GRAPH 400
CHARACTER NODES (RADICAL LAYER L^0)
PATH
RADICAL SET OR LAYER "L^i"
MEMBER
RADICALS
STROKE NODES (RADICAL LAYER L^N)

FIG. 4

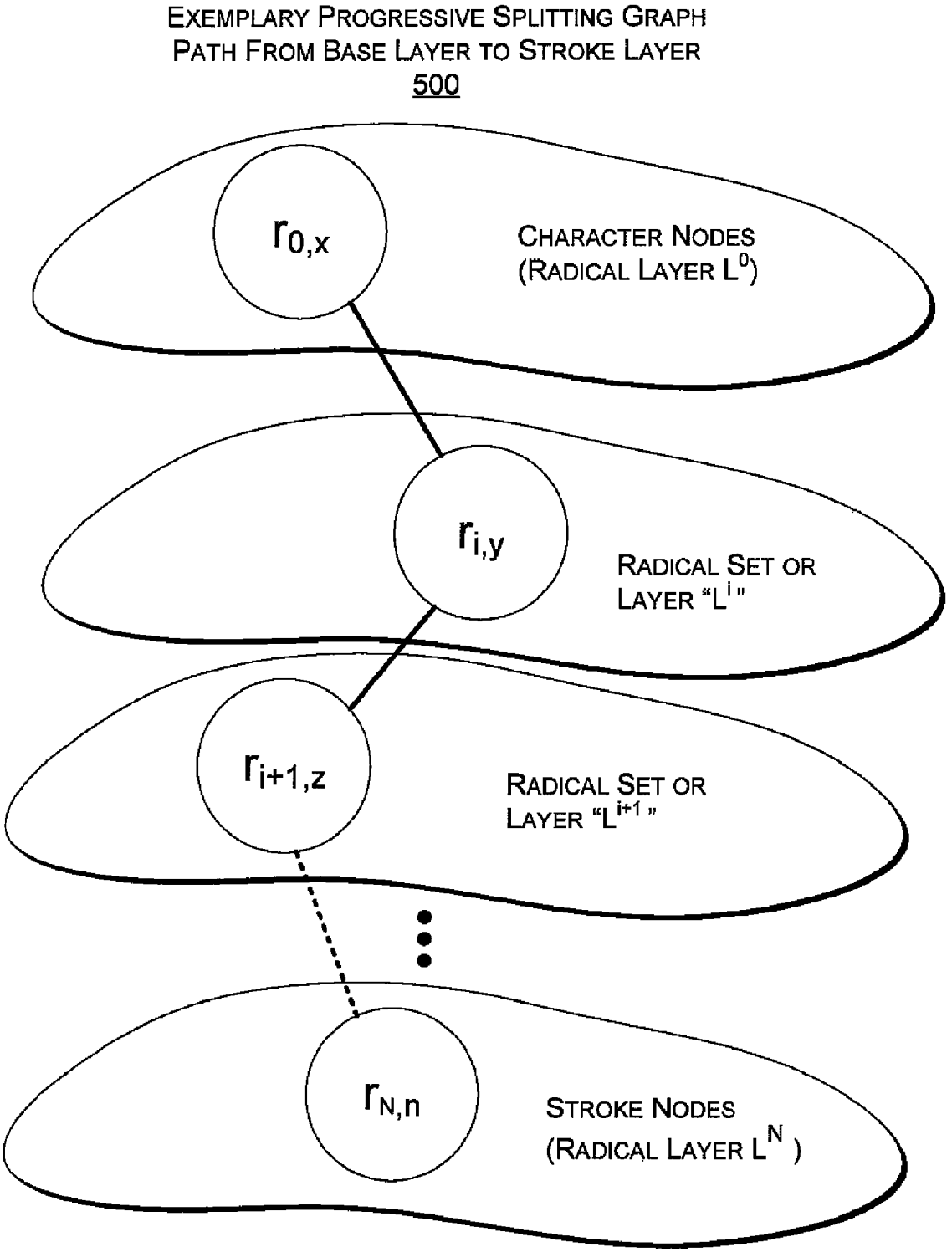

EXEMPLARY PROGRESSIVE SPLITTING GRAPH
PATH FROM BASE LAYER TO STROKE LAYER
500
$r_{0,x}$
CHARACTER NODES
(RADICAL LAYER L^0)
$r_{i,y}$
RADICAL SET OR
LAYER "L^i"
$r_{i+1,z}$
RADICAL SET OR
LAYER "L^{i+1}"
$r_{N,n}$
STROKE NODES
(RADICAL LAYER L^N)

FIG. 5

EXEMPLARY PROGRESSIVE SPLITTING GRAPH
PATH FROM BASE LAYER TO STROKE LAYER
600

CONDITION/CRITERION FOR COMPLETE ASSERTION:
$L \cap P \neq \emptyset$

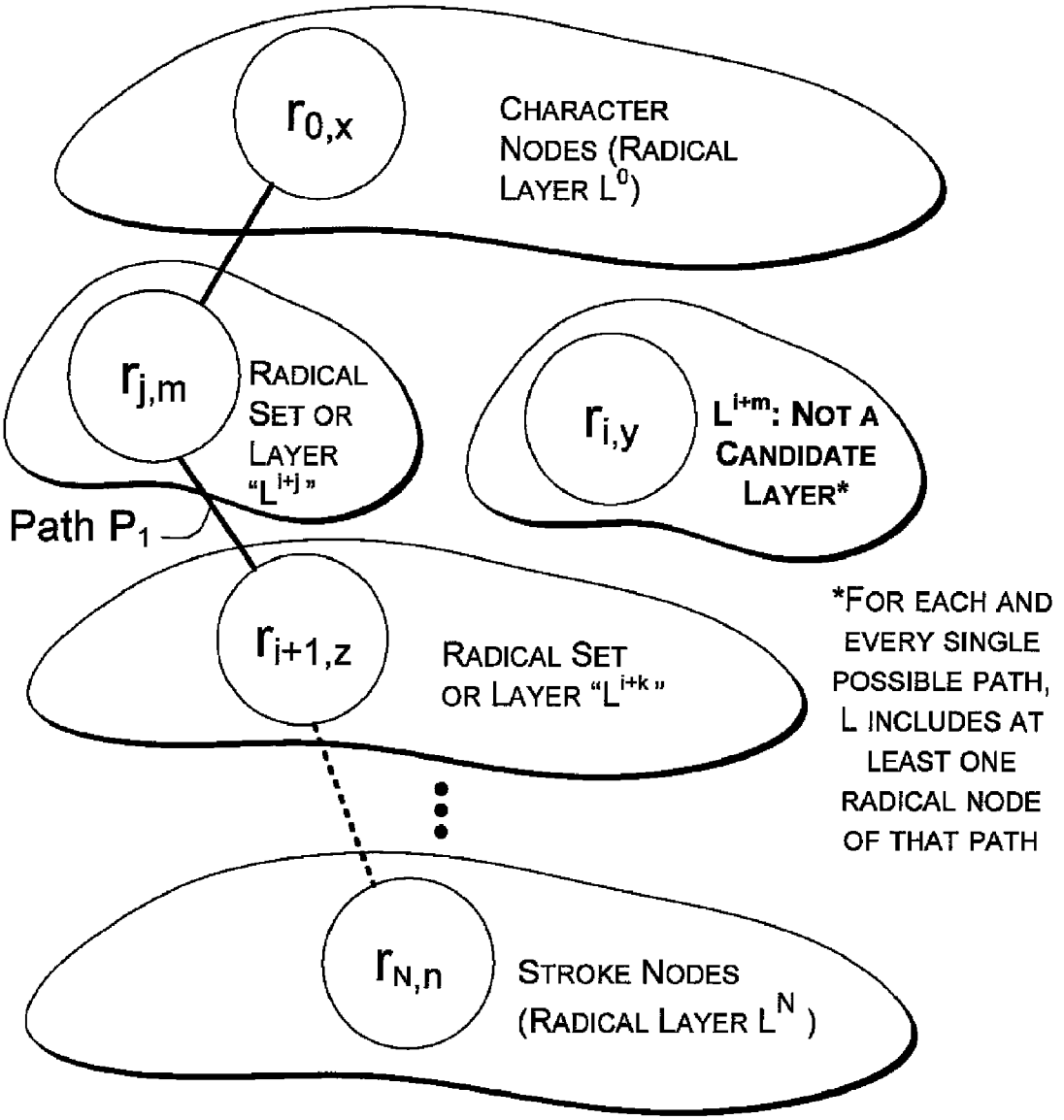
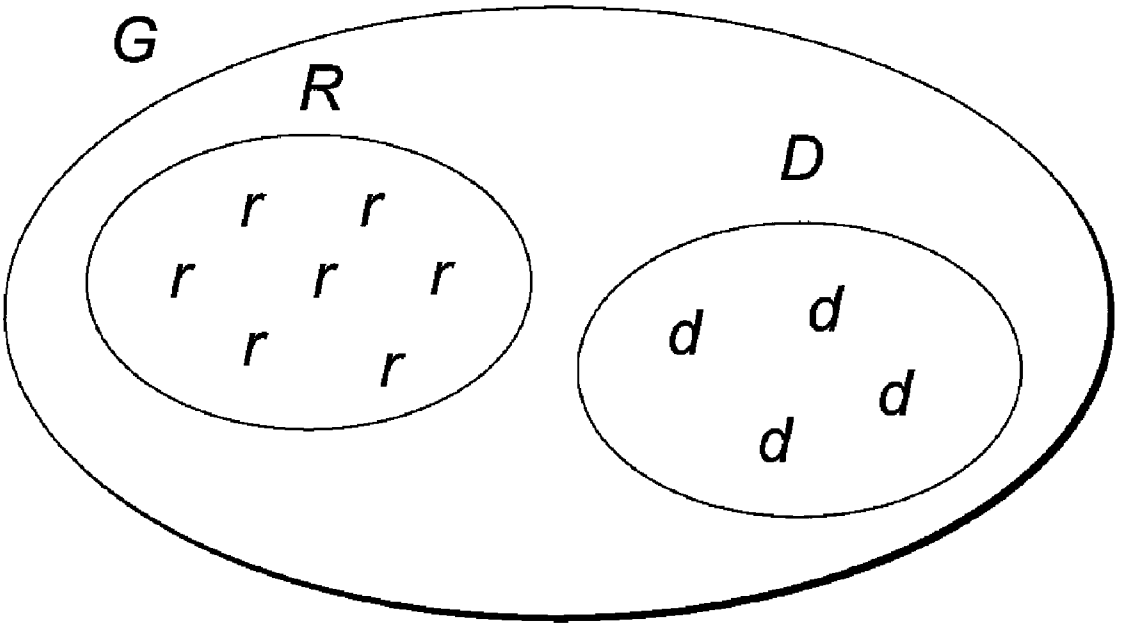


FIG. 6

EXEMPLARY ENUMERATION/SEARCH METHOD 700
(SEE, E.G., BLOCK 308 OF FIG. 3)
RADICAL GRAPH 710



RADICAL GRAPH CONDITIONS 720

$$d : r_d \rightarrow s_d$$

$$r_d \rightarrow s_{d,1}, s_{d,2}, \ldots s_{d,|d|}$$

$$r_d \rightarrow \mathbf{s}_d ; \text{members 1 to } |d|$$

($\mathbf{r} \rightarrow \mathbf{s}$; directly or indirectly)

$$u \rightarrow v ; \text{where } v \text{ in } \mathbf{s}_d$$

v is a child of u; i.e., v in set F(u)

FIG. 7

EXEMPLARY RADICAL EVALUATION METHOD 800
(SEE, E.G., BLOCK 312 OF FIG. 3)

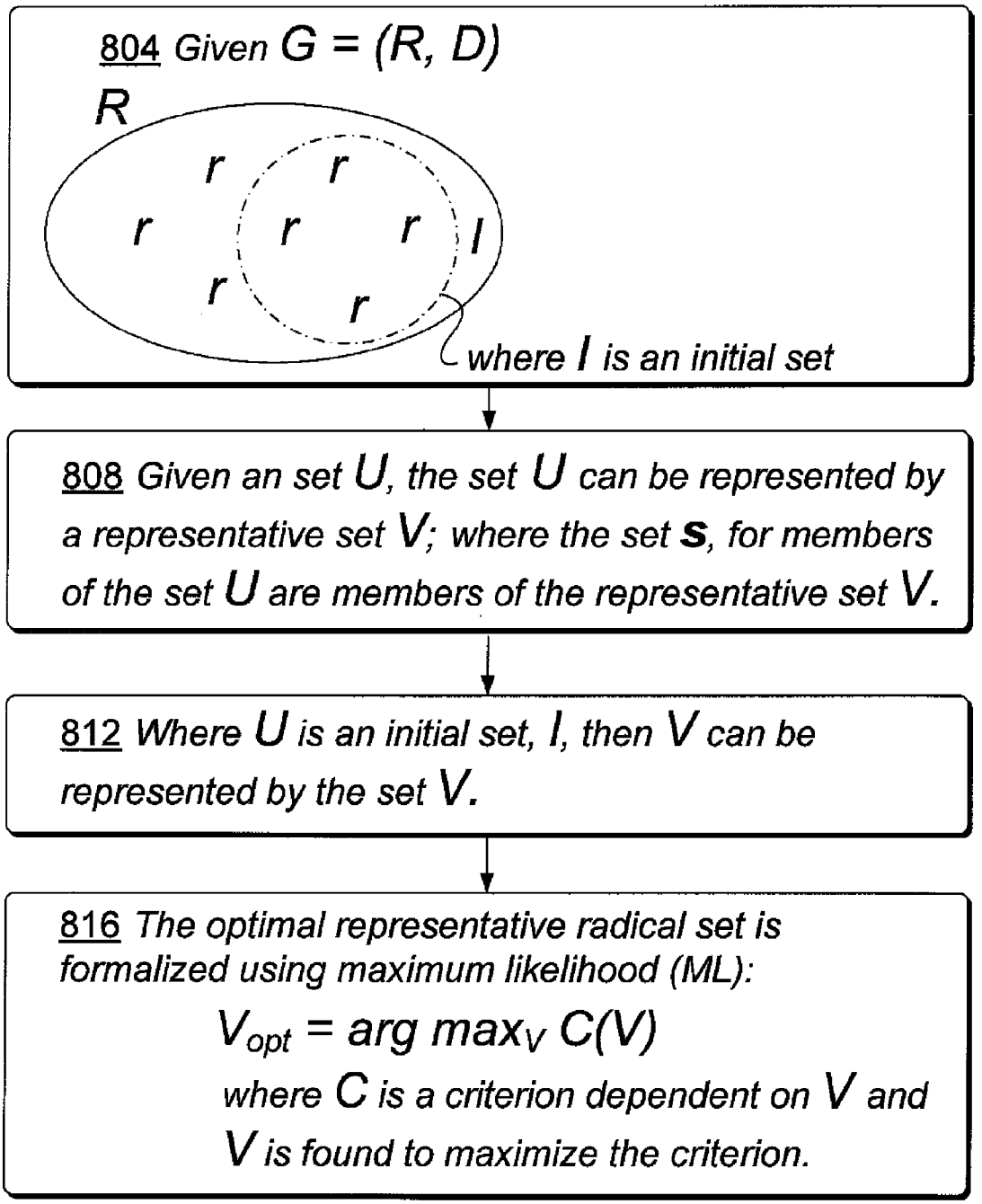


FIG. 8

EXEMPLARY RADICAL SET EVALUATION OPTIMIZATION FOR HMM USING MAXIMUM LIKELIHOOD CRITERION 900
(SEE, E.G., BLOCK 312 OF FIG. 3)

904 *To calculate likelihood, for each radical V in the set V, characterize each radical V (e.g., from 0 to N) using a left-to-right HMM* H_V^V.

908 *Modify the Criterion by Introducing a Penalty in the form of Minimum Description Length (MDL):*

$$C(V) = \underbrace{\int p_e(x)p(x|\Lambda^V)dx}_{PDF} - \underbrace{P(\Lambda^V)}_{MDL}$$

(Probability Density Function)

$$P(\Lambda^V) = 0.5*K(\Lambda^V)\log(Td_f)$$

where K *is the number of parameters in the HMMs,* T *is the number of training samples and* d_f *is the feature dimension.*

FIG. 9

RADICAL SET ENUMERATION/SEARCH METHOD 1000
FOR HMM USING MAXIMUM LIKELIHOOD CRITERION:
SIMPLIFICATION USING LAYERS
(SEE, E.G., BLOCK 308 OF FIG. 3)

1004 *Define Layers, including a base layer and a terminal layer and at least one intermediate layer between the base layer and the terminal layer.*

L^i { CHARACTER NODES AS RADICAL LAYER L^0 ; RADICAL SET AS RADICAL LAYER "L^i" ; STROKE NODES AS RADICAL LAYER L^N }

$$L^i = \begin{cases} L^0 & i = 0 \\ L^{i-1} \cup \left[\bigcup_{v \in L^{A,i-1}} \mathcal{F}(v)\right] - L^{A,i-1}, & i > 0,\ L^{A,i-1} \neq \phi \\ L^N & i > 0,\ L^{A,i-1} = \phi \end{cases}$$

1008 *Formulate Criterion using Defined Layers:*

$$i_{opt} = \arg\max_i \left[\int p_e(x) p(x|\Lambda^{Li}) dx - P(\Lambda^{Li})\right]$$

1012 *Find the optimal layer index, i_{opt}.*

FIG. 10

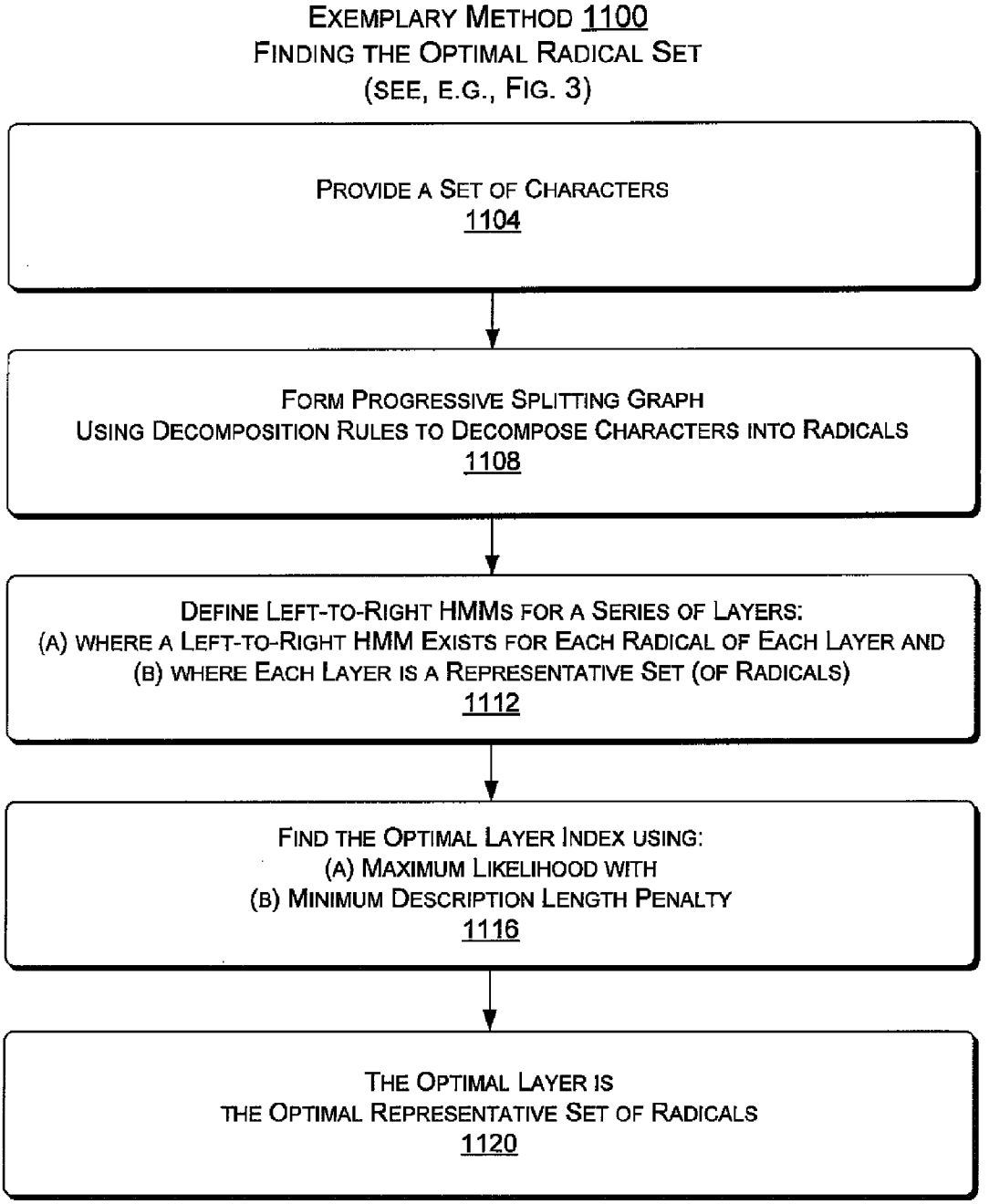

EXEMPLARY METHOD 1100
FINDING THE OPTIMAL RADICAL SET
(SEE, E.G., FIG. 3)
PROVIDE A SET OF CHARACTERS
1104
FORM PROGRESSIVE SPLITTING GRAPH
USING DECOMPOSITION RULES TO DECOMPOSE CHARACTERS INTO RADICALS
1108
DEFINE LEFT-TO-RIGHT HMMS FOR A SERIES OF LAYERS:
(A) WHERE A LEFT-TO-RIGHT HMM EXISTS FOR EACH RADICAL OF EACH LAYER AND
(B) WHERE EACH LAYER IS A REPRESENTATIVE SET (OF RADICALS)
1112
FIND THE OPTIMAL LAYER INDEX USING:
(A) MAXIMUM LIKELIHOOD WITH
(B) MINIMUM DESCRIPTION LENGTH PENALTY
1116
THE OPTIMAL LAYER IS
THE OPTIMAL REPRESENTATIVE SET OF RADICALS
1120

FIG. 11

EXEMPLARY LOCAL-TO-GLOBAL ALGORITHM FOR SELECTION OF A RADICAL SET
1200

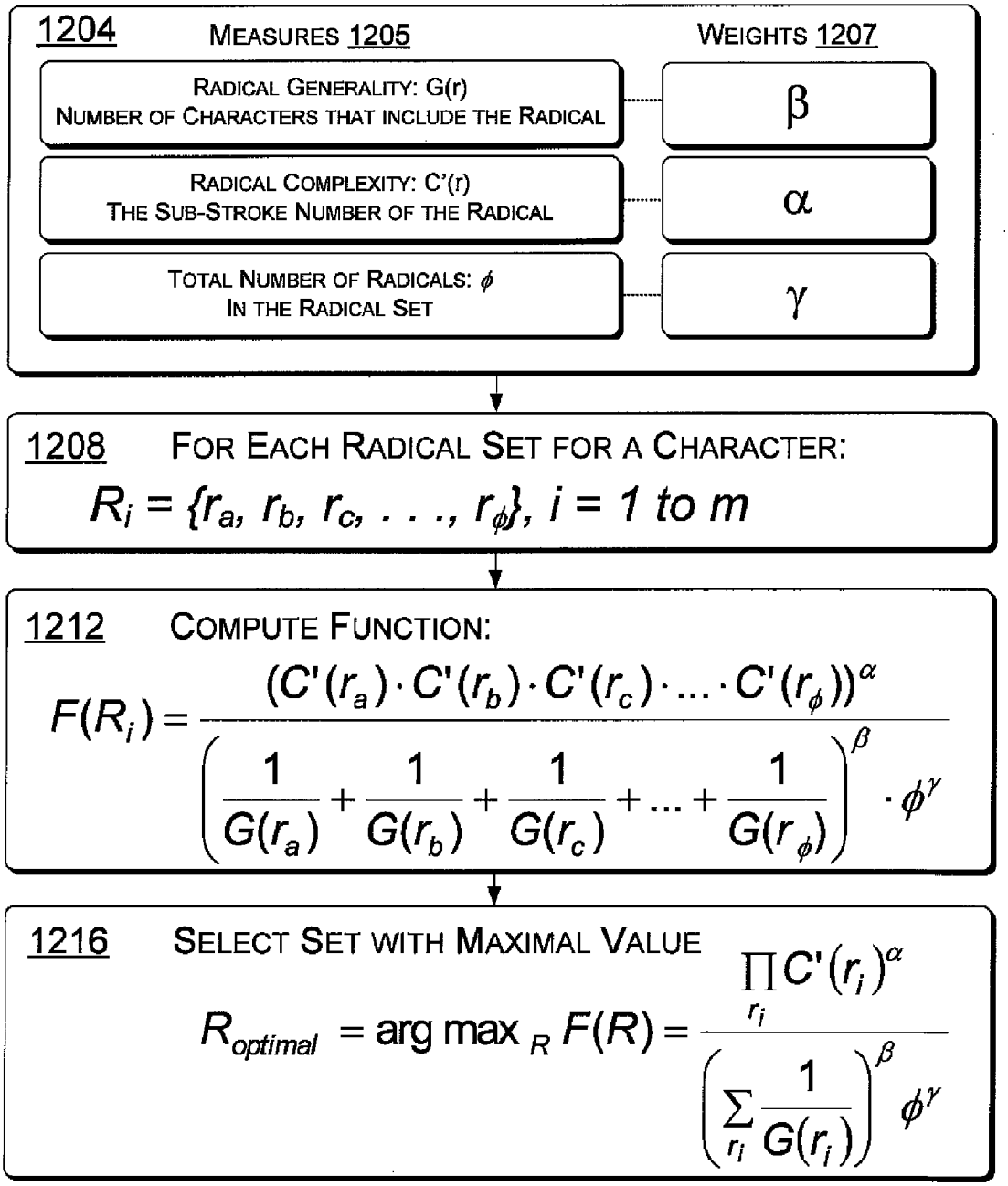


FIG. 12

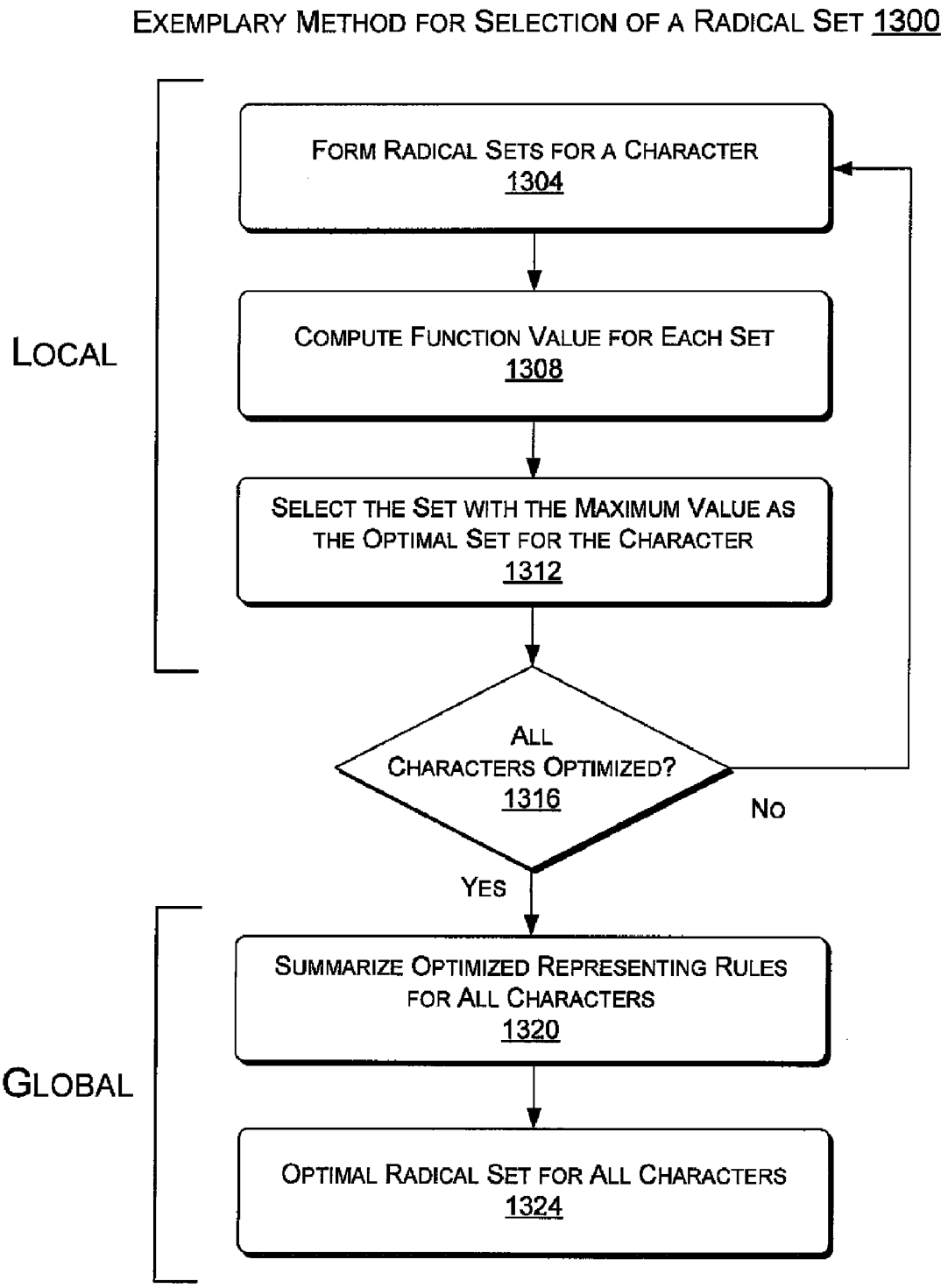

EXEMPLARY METHOD FOR SELECTION OF A RADICAL SET 1300
LOCAL
FORM RADICAL SETS FOR A CHARACTER 1304
COMPUTE FUNCTION VALUE FOR EACH SET 1308
SELECT THE SET WITH THE MAXIMUM VALUE AS THE OPTIMAL SET FOR THE CHARACTER 1312
ALL CHARACTERS OPTIMIZED? 1316
NO
YES
GLOBAL
SUMMARIZE OPTIMIZED REPRESENTING RULES FOR ALL CHARACTERS 1320
OPTIMAL RADICAL SET FOR ALL CHARACTERS 1324

FIG. 13

EXEMPLARY RADICAL SETS FOR A CHARACTER 1400

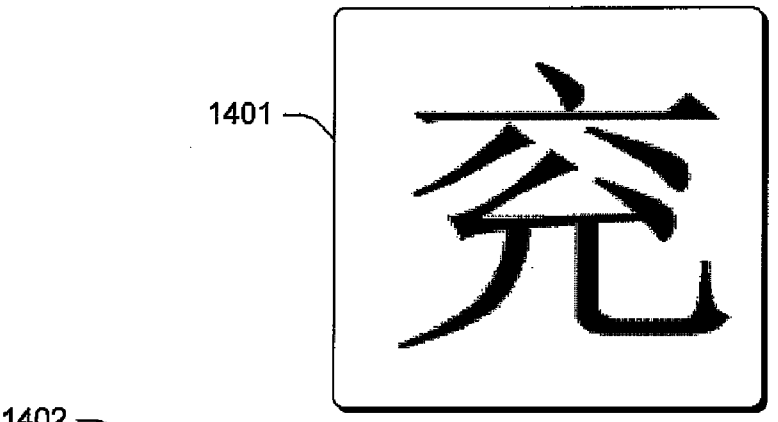


FIG. 14

EXEMPLARY METHOD FOR RADICAL SET SELECTION FOR A CHARACTER
1500

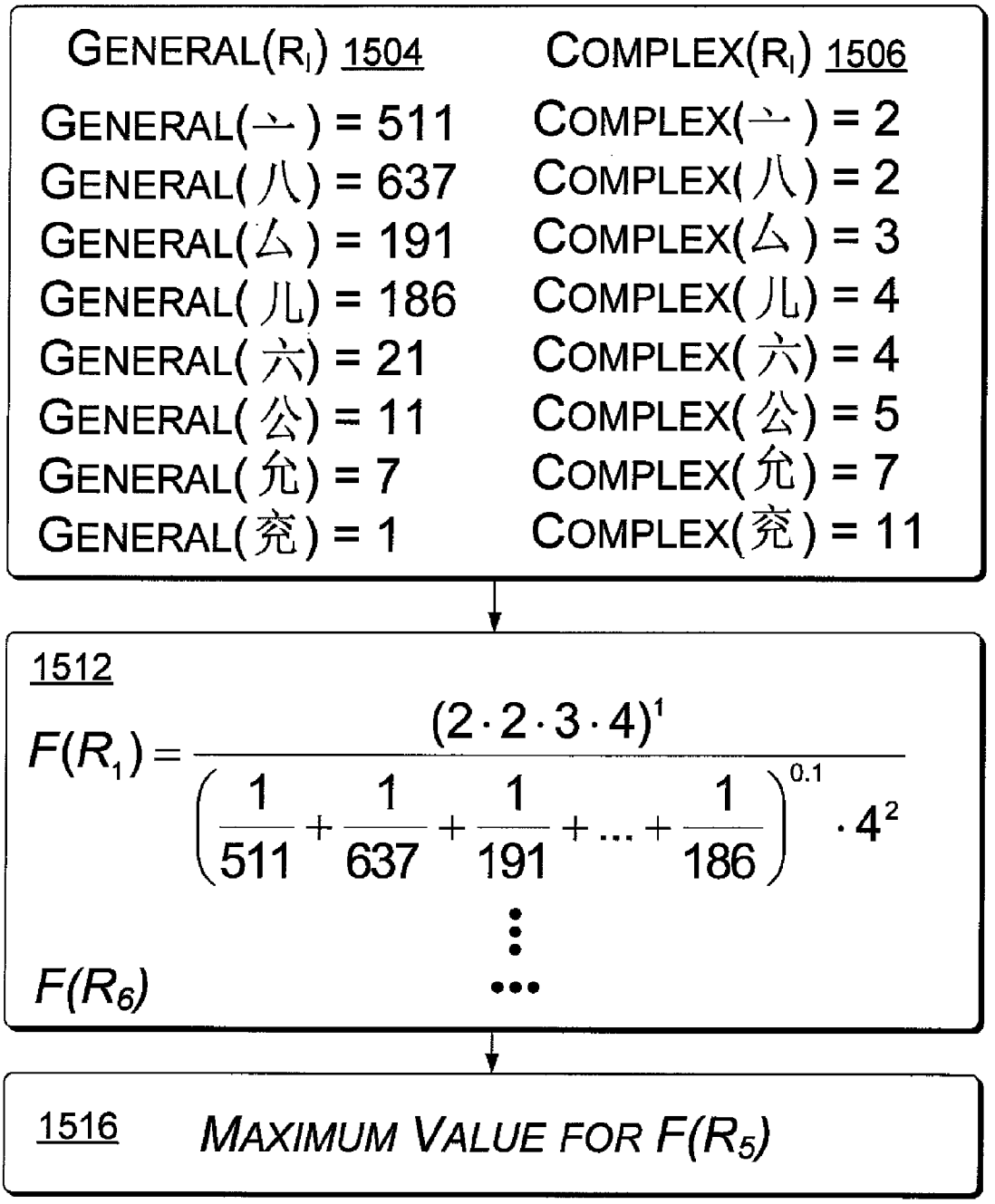


FIG. 15

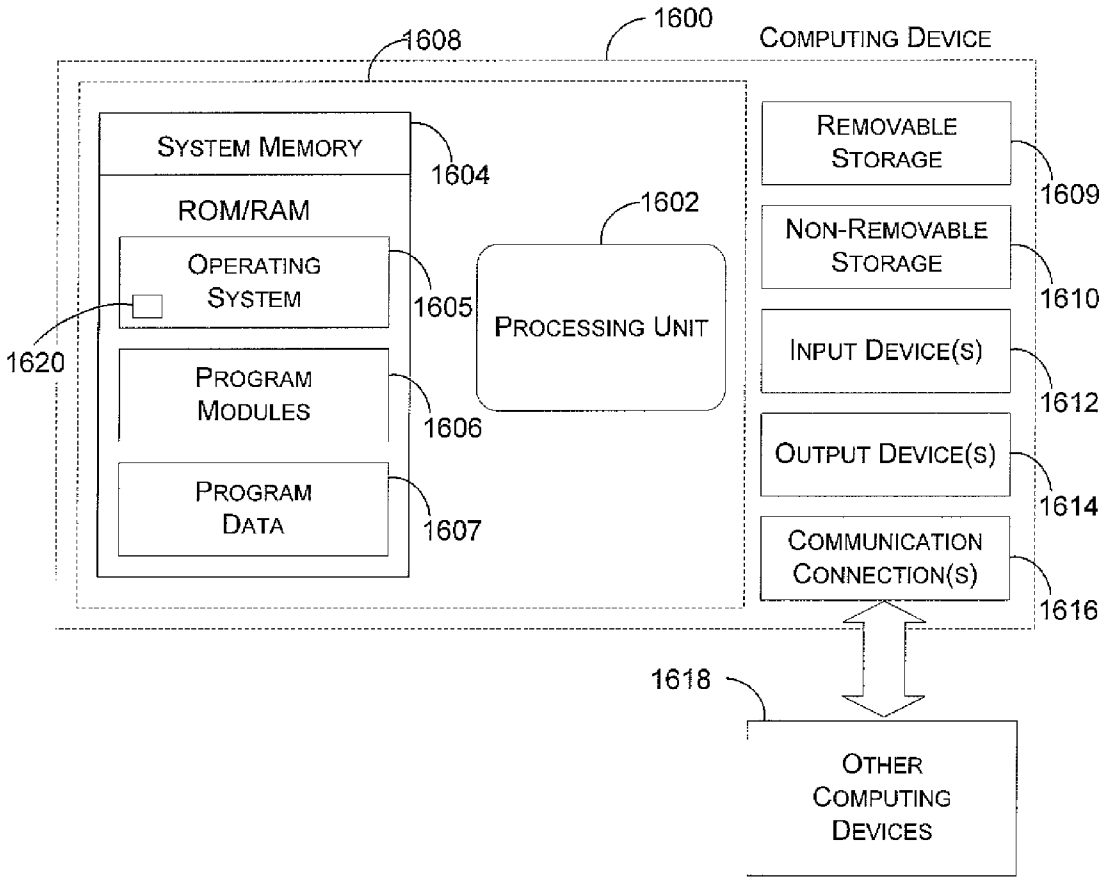

1600
COMPUTING DEVICE
1608
SYSTEM MEMORY
1604
ROM/RAM
OPERATING SYSTEM
1605
1620
PROGRAM MODULES
1606
PROGRAM DATA
1607
1602
PROCESSING UNIT
REMOVABLE STORAGE
1609
NON-REMOVABLE STORAGE
1610
INPUT DEVICE(S)
1612
OUTPUT DEVICE(S)
1614
COMMUNICATION CONNECTION(S)
1616
1618
OTHER COMPUTING DEVICES

FIG. 16

RADICAL SET DETERMINATION FOR HMM BASED EAST ASIAN CHARACTER RECOGNITION

BACKGROUND

East Asian (EA) language system is a complex system with a huge character set in comparison with the Latin letters. Taking Chinese for example, there are totally over 20,000 single characters. A recognition system with isolated models for each single character would be huge and include many redundant parameters. Implementation of a recognition system with isolated models on a handheld device would require significant resources to operate in a timely, efficient manner. Thus, a need exists for techniques to simplify recognition of EA characters.

SUMMARY

Exemplary techniques are described for selecting radical sets for use in probabilistic East Asian character recognition algorithms. An exemplary technique includes applying a decomposition rule to each East Asian character of the set to generate a progressive splitting graph where the progressive splitting graph comprises radicals as nodes, formulating an optimization problem to find an optimal set of radicals to represent the set of East Asian characters using maximum likelihood and minimum description length and solving the optimization problem for the optimal set of radicals. Another exemplary technique includes selecting an optimal set of radicals by using a general function that characterizes a radical with respect to other East Asian characters and a complex function that characterizes complexity of a radical.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

FIG. **1** is a diagram of an East Asian (EA) character along with indications of strokes and order of strokes.

FIG. **2** is a diagram of a general technique for character recognition using a probabilistic model along with some examples of computing devices that may implement all or part of such a technique.

FIG. **3** is a diagram of an exemplary method for finding an optimal radical set to represent EA characters.

FIG. **4** is a diagram of a progressive splitting graph (PSG) that includes EA characters and components of characters, referred to as radicals, where the PSG may be represented as various layers.

FIG. **5** is a diagram of an exemplary PSG where a path exists from a base layer to a stroke layer, typically a layer with the most rudimentary radicals.

FIG. **6** is a diagram of an exemplary PSG along with a condition or criterion for complete assertion for determination of one or more candidate layers capable of representing a character or set of characters.

FIG. **7** is a diagram of an exemplary enumeration and search method that includes use of a radical graph and conditions that apply to the radical graph.

FIG. **8** is a diagram of an exemplary evaluation method that includes use of a radical graph, as explained with respect to FIG. **7**, and a maximum likelihood (ML) formulation.

FIG. **9** is a diagram of an exemplary evaluation method that applies to radicals in Hidden Markov Models for EA character recognition and that includes a complexity penalty in the form of a minimum description length (MDL).

FIG. **10** is a diagram of an exemplary method for enumeration and search that includes layer representation of radical sets to simplify optimization and the overall model for EA character recognition.

FIG. **11** is a diagram of an exemplary method for finding an optimal radical set, which in this instance is also a layer.

FIG. **12** is a diagram of an exemplary method for selection of a radical set that includes use of generality and complexity measures.

FIG. **13** is a diagram of an exemplary method that includes use of generality and complexity measures on local basis to find local radical sets and then finds an optimal global radical set based on the local radical sets.

FIG. **14** is a diagram of an example of an EA character and some local radical sets for the EA character.

FIG. **15** is a diagram of an exemplary method that demonstrates how an optimal local radical set may be determined for the EA character and local radical sets of FIG. **14**.

FIG. **16** is a diagram of various components of an exemplary computing device that may be used to implement part or all of various exemplary methods discussed herein (see also, e.g., the computing devices of FIG. **2**).

DETAILED DESCRIPTION

As mentioned in the Background section, a need exists for more efficient character recognition systems, especially for East Asian (EA) characters (e.g., Chinese, Japanese, Korean, or the like). Two approaches to enhance efficiency of character recognition are described herein and referred to as: (i) a progressive splitting graph (PSG) technique and (ii) as a generality/complexity (G/C) technique. In general, an exemplary character recognition system will use one or the other technique to determine an optimal radical set that can represent a set of EA characters. However, where desired, an exemplary character recognition system may include use of a radical set selected using the PSG and a radical set selected using the G/C technique. During development of a character recognition system, a developer may test radicals sets determined through use of a PSG technique and through use of a G/C technique and then select the most appropriate set (e.g., for a given use). In general, the exemplary techniques presented herein are suitable for use in character recognition systems that rely on probabilistic models such as the Hidden Markov Model (HMM). In particular, radicals in an optimal radical set can be nodes for a HMM or possibly other types of probabilistic models (e.g., Bayesian models, etc.).

The PSG technique, as the name implies, uses a progressive splitting graph and layers to organize and optimize radicals that can represent EA characters. The G/C technique uses "local" generality and complexity measures to characterize radicals that represent an EA character and then uses a global optimization to select radicals to represent a set of EA characters.

An exemplary method may include providing a set of East Asian characters, applying a decomposition rule to each East Asian character of the set to generate a progressive splitting graph where the progressive splitting graph comprises radicals as nodes, formulating an optimization problem to find an optimal set of radicals to represent the set of East Asian characters using maximum likelihood and minimum description length, solving the optimization problem for the optimal set of radicals and using the optimal set of radicals in a Hidden Markov Model based character recognition algorithm.

An exemplary method may include providing a set of East Asian characters, for each East Asian character of the set, forming one or more sets of radicals and determining a value for each set of radicals based at least in part on a general function that characterizes a radical with respect to other East Asian characters of the set of East Asian characters and a complex function that characterizes complexity of a radical. According to such a method, for each East Asian character, the method may include selecting the set of radicals that comprises the largest value, determining an optimal set of radicals based on the selected sets of radicals for the set of East Asian characters and using the optimal set of radicals in a Hidden Markov Model based character recognition algorithm.

Details of the two aforementioned examples (the former a PSG example and the latter a G/C example) may be understood in more detail with reference to FIGS. **1-16**.

FIG. **1** shows a diagram of an East Asian (EA) character along with indications of strokes **100** and order of strokes **110**. Various end points of individual strokes are labeled from 1 to 6. In drawing the character, a person may form a corner or make an imaginary stroke. The simplest basic element set for an EA character is the set of strokes since all EA characters consist of strokes. However, strokes are typically too simple to form stable recognition models for EA characters. Another type of element is referred to herein as a radical, which is a stable structural unit that typically consists of several strokes (see, e.g., FIG. **4**), noting that an EA character is the most complex type of radical and that a simple single stroke is the most elemental type of radical. From both a language and character recognition point of view, an approach that uses some type of radicals between the complex and elemental ends of the spectrum has advantages over an approach that uses only elemental stokes. However, numerous radical sets exist that can completely represent an entire set of EA characters. Obviously, the simplest radical set is the elemental stroke set, which has the smallest model size but the poorest description precision. In contrast, the most complex radical set is the whole character set, which has the best description precision but also the largest model size. A proper radical set should balance model size and description precision. As described herein, the PSG technique and/or the G/C technique can be used to achieve such a balance. More specifically, various exemplary methods are described for selecting such a proper radical set and for defining representing rules of a whole character set based on a selected radical set.

FIG. **2** shows a general technique for character recognition **200** using a probabilistic model along with some examples of computing devices that may implement all or part of such a technique. The general technique includes selection of a probabilistic model **210** (e.g., a Bayesian model, HMM, or other type of probabilistic model), training of the model using training data **220** and implementation of the trained model **230**. Training data may be from individuals that have drawn the various characters or it may be generated data based on rules commonly used in drawing various characters.

FIG. **2** shows computing devices **201** and **205**, which may be a desktop computer and a handheld computer, respectively. The computing device **201** includes a display **202**, a keyboard **203** and a mouse **204**. The computing device **205** includes a display **206**, user input feature(s) **207** and a stylus **208**. In either example, a user may draw an EA character and the implemented trained model **230** may recognize the drawing (e.g., strokes) as being a particular EA character. In turn, the computing device may take any of a variety of actions (e.g., audible response, character selection and display response, etc.). As described herein the exemplary PSG and G/C techniques may be used to form a model for training and/or implementation.

FIG. **3** shows an exemplary method **300** for finding an optimal radical set to represent EA characters that uses a PSG approach. The method **300** commences with providing a set of characters and building a PSG **304**. Next, an enumeration block **308** enumerates every candidate radical layer by searching the PSG under a complete assertion criterion (see, e.g., FIGS. **7** and **10**). An evaluation block **312** then evaluates each enumerated candidate radical layer with a certain measurement (see, e.g., FIGS. **8** and **9**). A determination block **316** determines the optimal radical set as the radical set with the maximal measurement.

FIG. **4** shows a progressive splitting graph (PSG) **400** that includes EA characters and components of characters, referred to as radicals, where the PSG may be represented as various layers. With respect to the PSG **400**, a radical is a structural unit that includes several strokes. Further, a radical has to appear in at least one character or a character set. The PSG **400** is a data structure for representing the character structural hierarchy. The PSG is a directed graph, in which each node is a radical candidate and each directed arc emits from a radical candidate to one of its direct components. As already mentioned, the PSG **400** may be represented or defined on the basis of layers. For example, the PSG **400** includes a character nodes layer referred to as radical layer L^0, a radicals layer referred to as a radical set or layer L^i and a strokes nodes layer referred to as radical layer L^N. As indicated by the shaded layer L^i, a specific horizontal structural form is not required by a radical set layer. However, in general, various radicals of a radical set may be structured within a "horizontal" segment of a PSG due to application of rules to disaggregate a character into radicals.

FIG. **5** shows an exemplary PSG **500** where a path exists from a base or character layer L^0 to a stroke layer L^N, as already mentioned, typically a layer with the most rudimentary radicals. The path in PSG **500** passes through radicals or nodes in intermediate layers L^i and L^{i+1}.

FIG. **6** shows an exemplary PSG **600** along with a condition or criterion for complete assertion for determination of one or more candidate layers capable of representing a character or set of characters. In this example, path P**1** passes through intermediate layers L^{i+j} and L^{i+k} but not intermediate layer L^{i+m}. As indicated in FIG. **6**, for each and every single possible path, a candidate layer "L" must include at least one radical node of that path. Hence, the radical layer L^{i+m} is not a candidate radical layer. This condition or criterion may be represented as $L \cap P \neq \emptyset$.

Per the PSGs of FIGS. **4-6**, every character is split to several radical candidates, and then the radical candidates are recursively split until strokes. Such splitting relationships are represented by directed arcs. Per the condition of complete assertion, given a radical set L in a PSG graph, the radical set L is complete if all characters can be represented by the composition of members in L. The complete assertion condition is satisfies that L is complete, if and only if, for each path P from a character node (L^0) to a stroke node (L^N) in the PSG graph, $L \cap P \neq \emptyset$. A complete radical set is a radical layer, noted by L^i as the shaded region shows in FIG. **4**, again, where the character set and stroke set are both radical layers, noted by L^0 and L^N, respectively.

FIG. **7** shows an exemplary enumeration and search method **700** that includes use of a radical graph **710** and conditions that apply to the radical graph **720**. A hierarchical search in PSG graph involves radical layer propagation from L^0 to L^N given the criterion of complete assertion.

With respect to the radical graph conditions **720**, the radical graph is denoted as G=(R, D), where R is the radical set, and D is the direct decomposition rule set for decomposition of radicals (e.g., a character radical or other non-stroke radical). A direct decomposition rule "d" for decomposition of radicals (e.g., "d" belongs to the set "D") can be represented as d: $r_d \rightarrow s_d$, where r_d is within the set R and where s_d is belongs to the set $R^{|d|}$. The rule indicates that r_d can be decomposed to a sequence composed of |d| radicals $S_{d,1}, \ldots S_{d,|d|}$. Obviously, by applying direct decompositions iteratively, a series of decompositions of a radical can be obtained or generated. In FIG. **7**, r→s denotes that "r" can be decomposed to "s", directly or indirectly. Further, as indicated in FIG. **7**, given two radicals "u" and "v" as members of the set R, if there exists a rule d as a member of the set D satisfying r_d=u and v belonging to the set s_d, then v is called a child of u. The set of all the children of u is denoted as F(u).

FIG. **8** shows an exemplary evaluation method **800** that includes use of a radical graph, as explained with respect to FIG. **7**, and a maximum likelihood (ML) formulation. The method **800** commences with a graph provision block **804** that provides a graph as described with respect to FIG. **7**. A condition block **808** provides a condition that given a set U, the set U can be represented by a representative set V; where the set s, for members of the set U are members of the representative set V. Another condition block **812** provides a condition that where U is an initial set, I, then V can be represented by the set V. A formulation block **816** formulates an optimal formulation using maximum likelihood where a criterion C is dependent on V and where an optimum V (V_{opt}) is found to maximize the criterion.

Thus, according to the method **800**, given a radical set, members of the set can be decomposed or merged based upon a radical graph to maximize a certain criterion. An input radical set is termed the initial set and represented as I as contained within the set R (see block **804**). To facilitate representation, the concept of a representative set is introduced. Given a radical graph G and a radical set U within R, if every member of r within the set U there exists s that satisfies the condition that r can be decomposed to s and s is within the set V, then U can be represented with V.

As shown in block **816** of the method **800**, based upon the notations, the problem of optimal radical selection can be formulized as:

$$V_{opt}=arg\max_V C(V)$$

where C is the criterion to be defined. In a conventional training process for HMMs, maximum likelihood is widely adopted. As an example to demonstrate the PSG approach, the criterion C is defined based on maximum likelihood (ML).

FIG. **9** shows an exemplary evaluation method **900** that applies to radicals in HMMs for EA character recognition and that includes a complexity penalty in the form of a minimum description length (MDL). As indicated by the block **904**, for every candidate radical set V, and for each radical v in the set V, a corresponding HMM is provided (e.g., a left-to-right HMM H_v^V). The "likelihood" for evaluating the radical set is the likelihood of all training data on the HMM network. For different radical sets, this procedure is isolated. Therefore, different radical set have different HMM networks and independent likelihood evaluation.

In a criterion block **908**, a penalty is introduced to penalize model complexity. In other words, considering that the numbers of parameters can be different with respect to a particular radical set, model complexity should be penalized. In the example of FIG. **9**, the criterion of minimum description length (MDL) is adopted. The resulting criterion C(V) then includes a probability density function (PDF) component and a penalty component. The probability density function component includes a term "p_e" for the empirical distribution of data. In the block **908**, the symbol Δ represents the parameter set for the HMMs (see discussion of H_v^V above). As explained in the block **908**, the penalty function (MDL) includes a parameter K that represents the number of parameters in the HMMs and a parameter T, which is the number of training samples as well as a parameter d_f, as a feature dimension parameter.

FIG. **10** shows an exemplary method **1000** for enumeration and search that includes layer representation of radical sets to simplify optimization and the overall model for EA character recognition (see also, e.g., block **308** of FIG. **3**). In maximum likelihood sense, a combinatorial optimization problem exists given the criterion of block **908**. In solving such a problem, two general issues are (i) it can be computationally demanding to find the optimal solution by visiting all the feasible representative sets and (ii) even with a greedy search algorithm, such a problem is cumbersome to re-train the models at each step. Thus, the exemplary method **1000** uses an layer based optimization approach. As shown in FIG. **10**, the layer based approach uses a series of layers, which are some typical representative sets and, thus, model retraining is more practicable.

The method **1000** uses a layer approach to simplify searching for an optimal radical set. A definition block **1004** defines layers as including a base layer and a terminal layer with at least one intermediate layer between the base layer and the terminal layer. For example, the base layer may be an EA character layer while the terminal layer may be a stroke layer (see, e.g., PSG of FIG. **4**). Various criteria are shown using formalized mathematical representations for such a layer scheme. In these formulas, L^A represents the active set in set L (radical layers from L^0 to L^N). Each element in L^A should be a non-sink radical (e.g., a non-terminal radical), and for each element all the element's parents should not be in the active set L^A. Thus, for example, each element in the active set L^A should have children and no parent-child or ancestor-child pair exists in the active set L^A. The physical meaning of a step of layer evolution is to decompose all the radicals, except those children of other radicals in the current layer. In general, every layer L_i of FIG. **10** is a representative set of L^0. The layer sequence can generally describe the radical decomposition process, and the number of layers can be a relatively small number (e.g., on the order of approximately 10). Hence, re-training of the models Δ^{Li} for each layer can readily occur to obtain likelihoods. Block **1008** of the exemplary method **1000** of FIG. **10** shows a formulation of an optimization problem for the optimal layer. As indicated by block **1012**, by taking a layer approach (that considers layers as opposed to individual radicals, etc.), optimization can occur to find the best layer index. As described herein, the best layer can be used in a character recognition system for character recognition.

FIG. **11** shows an exemplary method **1100** for finding an optimal radical set, which in this instance is also a layer, for example, as described with respect to the method **1000** of FIG. **10**. In a provision block **1104**, a set of EA characters are provided. In a formation block **1108**, a PSG is formed according to decomposition rules to decompose the EA characters into radicals. As already explained, radicals of EA characters may be further decomposed to thereby expand the PSG. As the radicals are for use in a character recognition model, an appropriate model or models are chosen and defined. In the example of FIG. **11**, a definition block **1112** defines left-to-

right HMMs for a series of layers where (a) a left-to-right HMM exists for each radical of each layer and (b) where each layer is a representative set of radicals. As already mentioned, the problem may be formalized using maximum likelihood (ML) with a minimum description length (MDL) penalty. An optimization block **1116** finds the optimal layer by solving such a problem. The optimal layer is then selected in a selection block **1120** as the optimal representative set of radicals for use in recognition of the EA character set.

As mentioned, two techniques are described herein for selection of a set of radicals for character recognition. FIGS. **3-11** pertain generally to a PSG technique while FIGS. **12-15** pertain generally to a G/C technique. FIG. **12** shows an exemplary method **1200** for selection of a radical set that includes use of generality and complexity measures, i.e., G/C technique.

According to the G/C technique, each single EA character may have multiple representations. For example, an EA character may be represented by radicals r_a and r_b as well as by radicals r_a, r_d and r_h. The G/C approach can set forth optimized representations for each EA character and summarize representation rules to form an optimum radical set.

To establish the representing optimization problem for a EA single character, two measurement functions are defined as indicated in block **1204**:

Complex(r_a): measures the complexity of a radical r_a, which may be the sub-stroke number of the radical or other complexity measure;

General(r_a): measures the generality of a radical r_a, which may be the number of characters containing the radical or other generality measure. Block **1204** further includes a measure "ϕ", which is the number of radicals in a radical set. Further, weights **1207** (α, β, γ) may be assigned, for example, for use in a pre-determined function (see, e.g., function of block **1212**). Such weights may be optimized, adjusted or otherwise selected based on character recognition trials or one or more other criteria. The General function may operate using the Simplified Chinese GB0 character set, which includes 3755 characters. Where other character sets are used the General function may be different or otherwise adapted to accommodate the selected character set. Further, one or more weights may be adjusted accordingly.

Per the block **1208**, a single representing rule R (not to be confused with the radical set "R" of the PSG technique) includes a set of radicals (i.e., $R=\{r_a, r_b, \ldots, r_\phi\}$). Per block **1212**, a function "F(R)" is provided to compute a value for each radical set for each character. In the example of FIG. **12**, the function F(R) includes three weights, which appear as the weights **1207** in the block **1204**. Once function values are determined for each radical set for a particular EA character, then a selection block **1216** can select the set with the maximum function value ($R_{optimal}$). In turn, by summarizing the optimized representing rules of all characters an optimal overall or global radical set may be determined.

FIG. **13** shows an exemplary method **1300** that includes use of generality and complexity measures on local basis to find local radical sets and then finds an optimal global radical set based on the local radical sets. A formation block **1304** forms radical sets for a character. A computation block **1308** computes a function value for each radical set (see, e.g., the function of block **1212** of FIG. **12**). A selection block **1312** then selects the set with the maximum value as the optimal set for the character. As appropriate, and based on the number of characters in a character set, a decision block **1316** decides if the local process has been performed for each character. If not, then the method **1300** continues at the block **1304** otherwise the method **1300** continues in a global process.

The global process of the method **1300** includes a summarization block **1320** that summarizes optimized representing rules for all of the characters processed according to the local process (e.g., blocks **1304-1312**). Then an optimal radial set is selected in a selection block **1324** to represent all characters of the character set. For example, a process may picture out the optimized representations for each character and summarize the representation rules to form the optimal radical set. Such a radical set can then be used in any of a variety of character recognition systems. For example, the radical set selected by the block **1324** may be used in character recognition system that uses one or more HMMs.

FIG. **14** shows an example **1400** that includes some local radical sets **1402** for an EA character **1401**. More specifically, six radical sets are shown (R**1** to R**6**) where the number of radicals (ϕ) in any given set ranges from 1 to 4. Of course, the number of radicals in any given set for a particular character may be greater than 4 or less than four.

FIG. **15** shows an exemplary method **1500** that demonstrates how an optimal local radical set may be determined for the EA character **1401** and local radical sets **1402** of FIG. **14**. In the example of FIG. **15**, the General function **1504** is applied to the radicals to provide a generality value for each radical and the Complex function **1506** is applied to the radicals to provide a complexity value for each radical. A function block **1512** uses these values to compute a value for each set of radicals of the set **1402** from R_1 to R_6 of FIG. **14**. In the function block **1512**, the weights α, β and γ are assigned values 1, 0.2 and 2, respectively. As indicated in block **1212** of FIG. **12**, the weight α pertains to complexity, the weight β pertains to generality and the weight γ pertains to the number of radicals (ϕ) in a radical set R_i. In general, these weights maintain their values for all radical sets R_i under consideration (e.g., for a given character and/or for a set of characters). A selection block **1516** then selects the radical set that has the highest computed function value, which in this example is for radical set R_5.

While various examples refer to Chinese language characters, an exemplary PSG technique and/or an exemplary G/C technique may be used for a character set associated with a language such as Chinese, Japanese, Korean and the like. Hence, an optimal radical set may be suitable for use with a character recognition algorithm or system that provides for recognition of characters associated with Chinese, Japanese, Korean, or other languages. An exemplary character recognition system may be configured to recognize characters from one or more character sets.

FIG. **16** shows various components of an exemplary computing device **1600** that may be used to implement part or all of various exemplary methods discussed herein (see also, e.g., the computing devices of FIG. **2**).

The computing device shown in FIG. **16** is only one example of a computer environment and is not intended to suggest any limitation as to the scope of use or functionality of the computer and network architectures. Neither should the computer environment be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the example computer environment.

With reference to FIG. **16**, one exemplary system for implementing an exemplary character recognition system or a method for selecting a radical set for use in a character recognition system includes a computing device, such as computing device **1600**. In a very basic configuration, computing device **1600** typically includes at least one processing unit **1602** and system memory **1604**. Depending on the exact configuration and type of computing device, system memory

1604 may be volatile (such as RAM), non-volatile (such as ROM, flash memory, etc.) or some combination of the two. System memory 1604 typically includes an operating system 1605, one or more program modules 1606, and may include program data 1607. This basic configuration is illustrated in FIG. 16 by those components within dashed line 1608.

The operating system 1605 may include a component-based framework 1620 that supports components (including properties and events), objects, inheritance, polymorphism, reflection, and provides an object-oriented component-based application programming interface (API), such as that of the .NET™ Framework manufactured by Microsoft Corporation, Redmond, Wash.

Computing device 1600 may have additional features or functionality. For example, computing device 1600 may also include additional data storage devices (removable and/or non-removable) such as, for example, magnetic disks, optical disks, or tape. Such additional storage is illustrated in FIG. 16 by removable storage 1609 and non-removable storage 1610. Computer storage media may include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. System memory 1604, removable storage 1609 and non-removable storage 1610 are all examples of computer storage media. Thus, computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computing device 1600. Any such computer storage media may be part of device 1600. Computing device 1600 may also have input device(s) 1612 such as keyboard, mouse, pen, voice input device, touch input device, etc. Output device(s) 1614 such as a display, speakers, printer, etc. may also be included. These devices are well know in the art and need not be discussed at length here.

Computing device 1600 may also contain communication connections 1616 that allow the device to communicate with other computing devices 1618, such as over a network. Communication connection(s) 1616 is one example of communication media. Communication media may typically be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and includes any information delivery media. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media. The term computer readable media as used herein includes both storage media and communication media.

Various modules and techniques may be described herein in the general context of computer-executable instructions, such as program modules, executed by one or more computers or other devices. Generally, program modules include routines, programs, objects, components, data structures, etc. for performing particular tasks or implement particular abstract data types. These program modules and the like may be executed as native code or may be downloaded and executed, such as in a virtual machine or other just-in-time compilation execution environment. Typically, the functionality of the program modules may be combined or distributed as desired in various embodiments.

An implementation of these modules and techniques may be stored on or transmitted across some form of computer readable media. Computer readable media can be any available media that can be accessed by a computer. By way of example, and not limitation, computer readable media may comprise "computer storage media" and "communications media."

Referring again to FIG. 2, an exemplary computing device may include a processor, a user input mechanism (e.g., a mouse, a stylus, a scroll pad, a voice command, etc.), a display and control logic implemented at least in part by the processor to recognize an East Asian character based on a character recognition algorithm that uses a radical-based Hidden Markov Model wherein the radical set comprises a radical set selected using a technique that uses a progressive splitting graph or a technique that uses a general function and a complex function. Such a device may be a cellular telephone or generally a handheld computer. With respect to the control logic, the general function may characterize a radical with respect to other East Asian characters of a set of East Asian characters and the complex function may characterize complexity of a radical.

One skilled in the relevant art may recognize, however, that the techniques described herein may be practiced without one or more of the specific details, or with other methods, resources, materials, etc. In other instances, well known structures, resources, or operations have not been shown or described in detail merely to avoid obscuring aspects of various exemplary techniques.

While various examples and applications have been illustrated and described, it is to be understood that the techniques are not limited to the precise configuration and resources described above. Various modifications, changes, and variations apparent to those skilled in the art may be made in the arrangement, operation, and details of the methods and systems disclosed herein without departing from their practical scope.

What is claimed is:

1. A method comprising:

executing processor-executable instructions on a processing unit, the processor-executable instructions comprising:

providing a set of East Asian characters;

applying a decomposition rule to each East Asian character of the set to generate a progressive splitting graph where the progressive splitting graph comprises radicals as nodes;

formulating an optimization problem to find an optimal set of radicals to represent the set of East Asian characters using a maximum likelihood and a minimum description length, the minimum description length comprising a penalty that depends on a number of parameters in a Hidden Markov Model based character recognition algorithm;

solving the optimization problem for the optimal set of radicals; and

using the optimal set of radicals in the Hidden Markov Model based character recognition algorithm.

2. The method of claim 1 wherein the formulating comprises defining layers of radicals and wherein the solving solves the optimization problem for an optimal layer.

3. The method of claim 1 wherein the formulating comprises applying a complete assertion condition.

4. The method of claim 1 wherein the formulating comprises defining layers of radicals and wherein the set of East Asian characters form a base radical layer.

5. The method of claim 1 wherein the formulating comprises defining layers of radicals and wherein simple strokes form a terminal radical layer.

6. The method of claim 1 wherein the formulating comprises defining at least three layers of radicals.

7. The method of claim 1 wherein the minimum description length comprises an additional penalty that depends on a number of training samples for training a probabilistic model based character recognition algorithm.

8. The method of claim 1 wherein the applying applies a decomposition rule to an East Asian character of the set and applies a decomposition rule to a radical generated by decomposition of an East Asian character of the set.

9. A computer-readable storage medium comprising the processor-executable instructions to perform the steps of claim 1.

10. A method comprising:

executing processor-executable instructions on a processing unit, the processor-executable instructions comprising:

providing a set of East Asian characters;

for each East Asian character of the set, forming one or more sets of radicals and determining a value for each set of radicals based at least in part on

a general function that characterizes a radical with respect to other East Asian characters of the set of East Asian characters and a complex function that characterizes a complexity of the radical;

for each East Asian character, selecting the set of radicals that comprises the largest value;

determining an optimal set of radicals based on the selected sets of radicals for the set of East Asian characters; and

using the optimal set of radicals in a Hidden Markov Model based character recognition algorithm.

11. The method of claim 10 wherein the general function characterizes a radical according to a number of East Asian characters that include the radical.

12. The method of claim 10 wherein the complex function characterizes a radical according to a number of strokes in the radical.

13. The method of claim 10 wherein the determining determines a value for a radical set according to the function F:

$$F(R_i) = \frac{(C'(r_a)\cdot C'(r_b)\cdot C'(r_c)\cdot \ldots \cdot C'(r_\phi))^\alpha}{\left(\frac{1}{G(r_a)} + \frac{1}{G(r_b)} + \frac{1}{G(r_c)} + \ldots + \frac{1}{G(r_\phi)}\right)^\beta \cdot \phi^\gamma}$$

where R, is a set of one or more radicals (r_a, r_b, . . . r_ϕ,), C' is the complex function, G is the general function and α, β, γ are parameters.

14. The method of claim 13 wherein the parameters α, β, γ comprise adjustable weights.

15. A computer-readable storage medium comprising the processor-executable instructions to perform the steps of claim 10.

16. A computing device comprising:

a processor;

a user input mechanism;

a display; and

control logic implemented at least in part by the processor to recognize an East Asian character based on a character recognition algorithm that uses a radical-based Hidden Markov Model, wherein the radical set comprises a radical set selected using a technique that uses a progressive splitting graph or a technique that uses a general function and a complex function, wherein the general function characterizes a radical with respect to other East Asian characters of a set of East Asian characters and wherein the complex function characterizes a complexity of the radical.

17. The computing device of claim 16 wherein the computing device comprises a cellular telephone.

18. The computing device of claim 16 wherein the computing device comprises a handheld computer.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,805,004 B2
APPLICATION NO. : 11/680566
DATED : September 28, 2010
INVENTOR(S) : Shi Han et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 12, line 13, in Claim 13, delete "R," and insert -- R_i --, therefor.

Signed and Sealed this
Tenth Day of May, 2011

David J. Kappos
Director of the United States Patent and Trademark Office